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Risk Analysis And Marine Industry Standards

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ABSTRACT

Although the relation of risk and standards is not new, its definition is still unclear. The authors show how a framework established at the University of Maryland for the use of risk-based technology (RBT) methods in maritime regulatory activities could close the gap between risk and maritime industry standards. The authors will consider only one of the system performance characteristics -safety. Although other elements of system performance are equally important, their assessments could be accomplished using a similar framework and risk determination techniques.

INTRODUCTION

The marine transportation industry needs to improve its process and standards for designing the systems, subsystems, and components on which its operations depend. Major improvements in marine designs can only be expected if current processes and standards are greatly enhanced to consider systems engineering techniques capable of assessing risk. Current standard methods of evaluation used in the marine transportation industry are costly, labor-intensive, subjective, and incapable of repeatable and valid results. Programs like U.S. Coast Guard's Marine Safety Evaluation Program (MSTEP) and the University of Maryland's Risk, Safety and Decision for Marine Systems (RSDMS) will demonstrate the value of a better approach. This approach will grow out of proven engineering techniques, that relate well to common everyday problem solving and hazard evaluation processes. One-such process is the basic IPDE (Identify, Predict, Decide, Execute) technique taught by driving instructors to recognize and react to safety hazards on the road.

RISK AND STANDARDS

The relationship between risk and standards is not new and its definition is dependent on the point of view of the observer. To better appreciate this dilemma a closer look at the risk and standards from a historical perspective is needed.

Humanity has always sought to either eliminate or control unwanted risk to health and safety. Industries have achieved great success in controlling risk, as evidenced by advances made building methods for skyscrapers, long-span bridges and super tankers. Yet some of the more familiar forms of risk persist and continue to present a formidable challenge to both government and industry.

Ironically, some of the risks that are most difficult to manage are those that us with the greatest increase in our standard of living. The invention of the automobile, the advent of air travel and space exploration, the development of synthetic chemicals, and introduction of nuclear power all illustrate this point.

The need to help society cope with problems of risk gave rise to an intellectual discipline known as risk management. The complexity and pervasiveness of risk management requires cooperation of specialists from many fields of science and technology to combine their efforts in a holistic manner.

Within the U.S. government a milestone in technological research was attained in 1975 with the U.S. Atomic Energy Commission calling for nuclear reactor safety study, generally known as the "Rasmussen Report." The Rasmussen report was greeted with both great interest and substantial criticism. Some of the criticism involved valid technical concerns, some were adversarial reactions motivated by opposition to nuclear power. To obtain an independent evaluation and deal with the criticism the U.S. Nuclear Regulatory Commission appointed a second committee under the chairmanship of Professor Harold W. Lewis from the University of California. Lewis's report confirmed many of the technical criticisms of the Rasmussen report. However, despite these problems, Lewis concluded that the techniques developed and demonstrated in the Rasmussen study were "extremely valuable and should be far more widely applied in the process of regulating the nuclear industry." He further stated that "probabilistic techniques which provide guidance on the important issues in reactor safety, would be helpful in determining the priorities of the U.S. Nuclear Regulatory Commission both in its safety-research program and in the development of its regulatory and inspection resources." (Lewis, 1980).

When it comes to modern safety standards it is hard to pinpoint their exact origin. When penetrated, the maze of *civilized* trappings that are now part of our daily existence the public finds itself living in an environment devoid of trains, airplanes, skyscrapers, nuclear power plants, and super tankers. A flood of inventions, unprecedented in recorded history, catapulted 19^{th} century society into new and uncharted waters. Spearheaded by engineers, a torrent of new and wonderful machines began to pour into every element of the society. Engineers took pride in the growing superiority of American technology. However, they could not ignore the increasing death and injury statistics attributed to boiler-related accidents. Engineers from the American Society of

Mechanical Engineers (ASME) tackled the problem in 1884 by seeking reliable methods for testing steam boilers. This event marked a major milestone in the development of modern day test standards.

Because technology is being implemented in an ever-increasing pace it is imperative that standards keep pace with new materials, designs and applications. *Today's standard is not the last word, only the latest word*.

UNCERTAINTY TYPES

The analysis of an engineering system often involves the development of a model. The model can be viewed as an abstraction of certain aspects of the system. In performing this abstraction, an engineer must decide which aspects to include and which to exclude. Figure 1 shows uncertainties in these aspects that can make model development difficult. Also, depending on the state of knowledge about the system and the background of the engineer, unknown aspects of the system might substantially increase the overall level of uncertainty. Aspects of the system fall into three categories, i.e., abstracted, non-abstracted, and unknown amongst witch several types of uncertainty can be present. Figure 1 provides examples of uncertainties within each category.

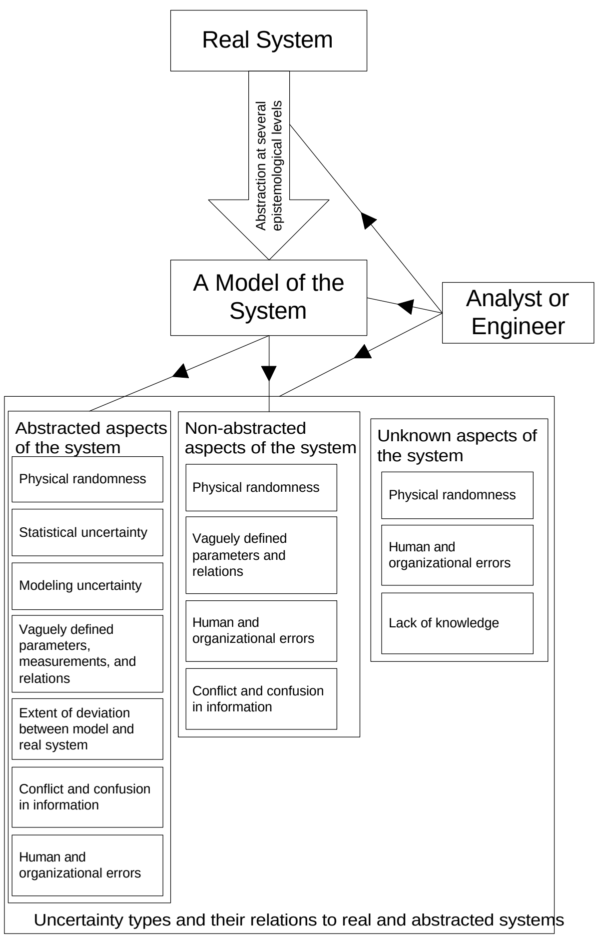

Figure 1. Uncertainty types for engineering systems

Uncertainties in engineering systems are mainly attributed to ambiguity and vagueness in defining design and performance parameters of the systems and their interrelationships. The ambiguity component is generally due to the following sources, which include:

(1) Physical randomness;
(2) Statistical uncertainty due to the use of limited information; and
(3) Model uncertainties that are due to simplifying assumptions, simplified methods, and idealized representations of real performances.

The vagueness-related uncertainty is due to the following factors:

(1) The definition of parameters, e.g., structural performance, quality, deterioration, skill and experience of construction workers and engineers, environmental impact, and conditions of existing structures;
(2) Human factors; and
(3) The inter-relationships between the design and performance parameters of complex systems.

Objective Types

Engineers and researchers normally handle ambiguity and uncertainty in predicting the behavior of engineered systems by using existing theories of probability and statistics. Probability distributions are used to model system parameters that are uncertain. Probabilistic methods that include reliability-based methods, probabilistic engineering mechanics, stochastic finite element methods, and random vibration were developed for this purpose. In this treatment, however, a realization of a subjective type of uncertainty was established. Uniform and triangular probability distributions are often used to model this type of uncertainty. Bayesian techniques have also been used to model these parameters. The underlying distributions and probabilities were then modified to reflect this increase in knowledge. Regardless of the nature of the information, whether it was subjective or objective, the same mathematical assumptions and tools are used.

Subjective Types

Subjective types of uncertainty arise from inconsistencies inherent in human derived abstractions of reality required to simulate complex systems. These abstractions lack crispness and precision. Vagueness is distinct from ambiguity in source and natural properties. The axioms of probability and statistics are limited for this type of modeling and analysis, and may not be relevant. Therefore, vagueness is best modeled using fuzzy logic theory. In engineering, fuzzy logic has to be a useful tool in solving problems that involve this type of uncertainty. For example, these theories have been successfully used in:

- Strength assessment of engineered structures
- Risk analysis
- Analysis of construction failures, scheduling of construction activities, safety assessment of construction activities, decisions during construction and tender evaluation
- The impact assessment of engineering projects on the quality of wildlife habitat
- Planning of river basins

- Control of engineering systems
- Computer vision, and
- Optimization based on *soft* constraints.

CONSIDERATION OF RISK

It is known that “risk” affects the gambler about to roll the dice or the acrobat taking his first jump. But with these simple illustrations aside, the concept of risk comes about due to recognition of future uncertainty -- our inability to know what the future will bring in response to a given action. Risk implies that a given action has more than one possible outcome.

In this simple sense, every action is "risky", from crossing the street to operating a ship. The term is usually reserved, however, for situations where the range of possible outcomes is in some way significant. Common actions, like crossing the street don’t usually imbibe as much risk as complex actions, such as operating a ship. Somewhere in between, actions pass through thresholds that differentiate them as either being low risk or high risk. Figure. 2 below depicts symbolic notions of risk where sailing in a small boat could inherently be more risky than aboard an ocean liner. This distinction, although vague, is important -- if one judges that a situation is risky, risk becomes one criterion for deciding what course of action you should pursue. At that point, some form of *risk assessment* becomes necessary.

$$\text{RISK} = \frac{\text{HAZARD}}{\text{SAFEGURDS}} = \frac{\text{ocean}}{\text{ship size}} = \frac{H}{S}$$

$$R = R_1 + R_2 = \frac{H_1}{S_1} + \frac{H_2}{S_2}$$

Figure 2. Symbolic Equations of Risk

Characterization of Risk.

Risk derives from the inability to accurately predict the future, and indicates a degree of uncertainty that is significant enough to be noticed. This definition takes on additional meaning by concidering several important characteristics of risk.

First, risk can be either objective or subjective. The former refers to the definitive product of scientific research. The latter refers to non-expert perceptions of that research, and can be significantly altered by the consideration of whatever is occupying the public mind or body politic at the particular moment in time. This distinction is important in how it characterizes both public opinion and the opinion of experts.

Although it is tempting, and quite common, to attribute disagreements between the public and the experts to public ignorance or irrationality, closer examination often suggests a more complicated situation. Conflicts often can be traced to differences in perspective and definitions such as what the true meaning of risk is and how it applies to the unique circumstances of both camps. When the public proves to be misinformed, it is often for good reason, such as receiving faulty information through the news media or from the scientific community. In some instances, members of the public may have a better understanding of certain issues than the experts, but are unable to draw the right conclusions due to lack of knowledge about the use of existing risk assessment tools.

Along with these objective elements found in public opinion, there are inevitably elements of subjectivity to be found in expert estimates of risk. Standard definitions of objectivity typically refer to the independence of the observer as a critical component. Thus, different individuals following the same procedure should reach the same conclusion. However noble as a goal, this sort of objectivity can rarely be achieved. Particularly in complex areas, such as risk analysis, expert judgment is usually required. Even in those orderly areas for which statistics are available, interpretative questions must be answered before current, or even historical, risk levels can be estimated. This is the case in such circumstances as temporal trends, e.g., whether or not another major oil spill is imminent and predisposed causes, e.g., where questions of crew, or human incompetence need to be addressed. Total agreement on such issues is a rarity. Thus, objectivity should always be an aspiration, but never assumed as a given. When the public and experts disagree, it is a clash between two sets of different opinions. It is important to recognize that experts, differing in their definitions of risk, will also differ in how they acknowledge the role of judgment in risk assessment.

Flipping a coin is an objective form of risk because the odds are well known. Even though the outcome is uncertain, an objective form of risk can be described precisely based on theory, experiments, or common sense. Most agree with this description of objective risk. Describing the odds for thunderstorms to develop on any given day is not as clear cut, and represents a subjective form of risk. Given the same information, theory, and computers, etc., one weatherman may think the odds of thunderstorms are 20% while another weatherman may think the odds are 50%. Neither is wrong. Describing a subjective risk is open-ended in the sense that one could always improve the assessment with new data, further analysis, or by lending more credence towards other professional opinions. Most risks are subjective, and this has important implications for those assessing risk or making decisions based upon risk assessments.

Deciding that something is risky often requires personal judgment, even for objective risks. For example, one flips a coin and wins \$1 if its heads and loses \$1 if its tails. The personal risk of winning \$1 or losing \$l would not be overly significant to most people. However, if the stakes were much higher (e.g., \$10,000), most people would find this situation to be quite risky. There would still be a few individuals who would not find this range of outcomes to be significant, but the majority of individuals would probably find it intolerable.

Most people differ in the amount of risk they are willing to take. For example, two individuals of equal worth may react quite differently to the \$10,000 coin flip. People will differ widely in their preferences, or tolerances, for risk primarily due to their unique set of personal experiences and current station in life.

Defining Risk Analysis

Risk analysis is the process of evaluating the degree of risk inherent in a particular situation a pre-established set of criteria. There is consensus among experts that a comprehensive risk

analysis consists of three major components: risk assessment, risk management, and risk communication.

Risk assessment is essentially the process of deciding how dangerous a hazard is. The first step in the process of risk assessment is to identify and qualitatively describe the hazards within a given situation that are to be assessed. Next, the level of exposure to the hazardous activity is assessed. Along with that the response of the people and systems in question is assessed to different hazard intensity levels. Finally, the above information is combined to characterize the risk in quantitative terms. While no risk assessment is devoid of value judgments, the task should be as objective and consistent as possible.

Risk management is the process of selecting alternatives and deciding what to do about an assessed risk. Risk management, unlike risk assessment, involves consideration of a wide range of factors including: engineering, economic, political, legal and cultural aspects pertaining to the specific hazardous condition in question.

Risk communication is the process by which organizations and individuals exchange information about risk. Because perceptions of risk and its consequences, often differ widely, risk communication typically requires a heightened level of sensitivity and mutual respect between all parties involved to ensure that a genuine dialogue exists and can be maintained over time.

Qualitative vs. Quantitative Risk Assessments

The controversy surrounding the use of quantitative vs. qualitative risk analysis methods is not new. The Center for Building Systems and Technologies located at the University of Maryland recommends blending of the two methods. The qualitative analysis can always be made more quantitative by defining probabilities in a more numeric manner if sufficient data exists. The quantitative analysis can always be simplified if discrete levels of risk and reliability are substituted for actual numeric values. In many real-world circumstances this type of blending technique is the only way to satisfy the requirements of various stakeholders while operating in a less than ideal data environment.

Furthermore, preferred hazard controls or system safeguards can only be matched to the risk level if an initial quantitative analysis is done. Therefore, in most cases a certain level of both qualitative and quantitative analysis is required to fully comprehend the inherent risk within a specified system. No matter what method is used, it is important to view the entire system as a whole and not simply as a number of unrelated pieces or components.

A top-down scenario-based qualitative approach is advocated for initial risk assessments involving the maritime industry. This allows the industry to focus its remaining resources on quantitative assessments of those marine systems that are the primary contributors to safety at sea. Based on general experience and readily available information the qualitative analyses are first performed to identify hazard scenarios, and to categorize these scenarios on the basis of likelihood and consequence. The output of this first step is a priority ranking of hazard scenarios and recommended actions that address each risk category.

As a second step, quantitative risk assessment (QRA) of selected scenarios may be necessary to refine the understanding of the most significant contributors to risk, and to provide an adequate basis for recommended actions, as in the form of design or operational enhancements to mitigate or control the underlying risk. In most cases the collection of data for quantitative analysis will begin once the results of a qualitative assessments are available and a reasonable safety management and communication effort are underway. The output of this step is (1) a quantitative definition of the absolute and relative risks, with explicit treatment of the underlying uncertainty. In addition, a more rigorous definition of the major contributors to risk is also obtained. The combined results provide an understanding of the benefits and costs of various risk-reduction alternatives. This is the essence of MSTEP's risk assessment logic engine, the Engineered Marine System Assessment (EMSA) methodology, being developed at the Center for Building Systems and Technologies at the University of Maryland. As shown in Figure 3, EMSA is built around an iterative process of risk assessment and risk management techniques in which both qualitative and quantitative methods are used to provide a logical basis for balancing risk and economic considerations.

Quantification of risk is as much a process of identifying what is known as it is of quantifying what is unknown. With respect to EMSA, quantification of marine risks must be achieved using less-than-perfect data. Thus, in quantifying frequency of occurrence and consequences, it is necessary to compile all forms of evidence, e.g., historical evidence, expert opinion, and experience with similar systems or events. Finally, the results are presented in a manner that makes them explicit in terms of an in-depth understanding of the underlying risks. Unfortunately, for the maritime industry, the likelihood of having collected the right types of hazard-related data prior to establishing a risk management program is extremely low. Hopefully, this will not be the case in the future as the industry migrates to risk-based forms of safety assessments.

STANDARDS AND CRITERIA

Although the dictionary indicates a number of applicable meanings to the word "standard," only two are

relevant here; one, as the basis for measure of physical properties, and two, as the norm for common or accepted practice.

In the United States, the phrase of *laisse-faire*, or freedom of choice coupled with a lack of uniform standards continues to have considerable negative impact on safety and economic viability of U.S. marine industry. An example of this is the fact that most of the world uses the metric system while the United States still uses the English system, thus condemning U.S. products to suffer under the banner of having-poor integration qualities.

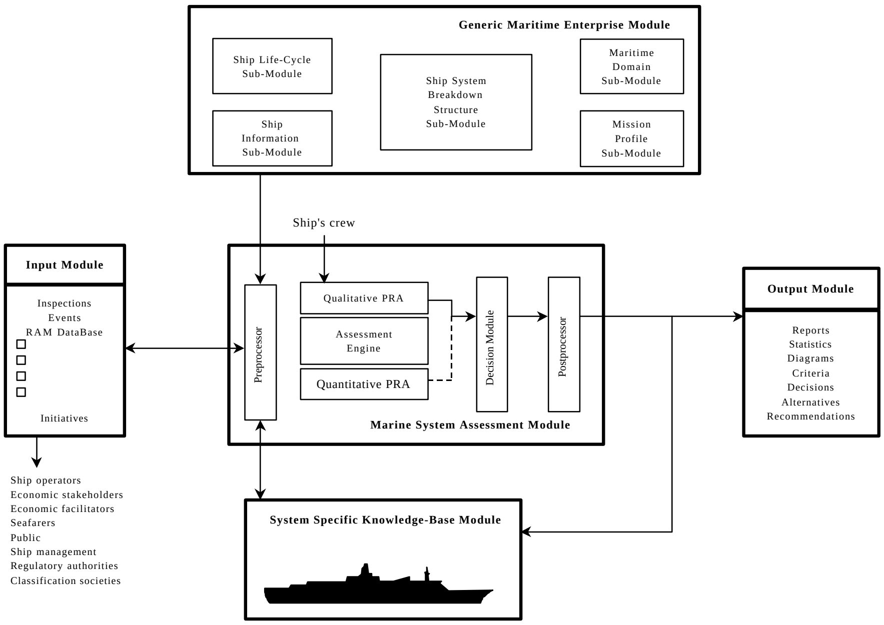

Figure 3. Engineered Marine System Assessment (EMSA) Methodology (Karaszewski et al 1992)

with systems built elsewhere in the world. In other industrialized countries, the use of uniform standards has avoided most of the problems currently being experienced in the United States. These standards not only improve safety but also reduce the costs of these products and affect the entire value chain associated with these products within their native economies In addition, these uniform standards allow greater flexibility in making improvements, regardless of whether they are government-mandated or market driven.

Objection to Standards

The United States is extremely cautious in setting or adopting standards, especially those of a mandatory nature. This is the result of a national paradigm that is heavily influenced by tradition and upon the belief that standards lead to inferior quality products and obfuscate the market's ability to exercise freedom of choice. Unfortunately, this is still the way that many U.S. managers feel when they have to meet requirements set by mandatory standards. Imposition of requirements, irrespective of their true merit, is frequently met with great amount of reluctance. This is primarily due to the level of effort it takes to understand the basis for these requirements and assimilate them into their existing processes. The new criteria are perceived as being inconvenient, and subject to creating delays or adding costs. Modern U.S. management also treats the integration of mandatory standards as a collateral duty for its line managers thereby downplaying their significance to the organization and more importantly to the marketplace. In many instances, failure to meet these mandatory requirements has also resulted in litigation. For these reasons, designers and managers prefer voluntary standards since they can be ignored or accepted at the discretion of each individual organization without any fear of future legal entanglements. In this voluntary mode of standards implementation, managers are accepting on behalf of their organizations what they believe to be a low probability of a serious casualty occurring while averting the intent and spirit of rigorously developed standards. Just how much risk is

being assumed in this manner is hard to establish. However, it is fairly plain to see that this form of risk management is extremely shortsighted. It represents a form of professional procrastination and a meager attempt to forestall the inevitable both of which are not healthy indicators of world-class statue and performance.

Benefits of Standards

Putting aside the reasons for imposing voluntary or mandatory standards, recognition of standards is beneficial to engineers and the public in many ways. A standard often contains useful technical information that engineers will find helpful. A standard promotes consistency and identifies basic levels of safety and dependability in similar systems, equipment, materials, or operations. It helps eliminate the need to search for information that is already resident in the standard, through rigorous screening and incorporation of past experiences. The criteria, or requirements, found within standards were developed to avoid the recurrence of undesirable events or hazardous circumstances that had the potential to cause accidents. Through careful consideration standards were prepared to avoid situations that could develop into problems. Only through careful consideration can the appropriate precautions be taken. In many cases, standards often indicate to designers what should *not be done*. Standards help decide whether a proposed design is safe or not, and assist in making decisions regarding the selection of hazard controls. They help reduce differences in opinion between engineers, manufacturers, regulators, and others concerning levels of safety, types of equipment to be used, mitigation measures to be observed, and safeguards to be incorporated. Potential benefits in the use of standards are:

- Reduction of accidents.
- Maintenance of acceptable levels of safety.
- Establishment of acceptable industrial practice.
- Reduction of legal actions.

Standards and the Courts

The significance of standards when applied to matters of marine safety, is normally that of an indicator of whether the actions of a specific party have been negligent with respect to established levels of safety. Regulators have indicated that a judicious person will normally adhere to rules, processes and procedures that conform to an acceptable level of safety. This acceptable level of safety, in most cases, is what others believe to be a normal or acceptable level of conduct within the recent past. Violation of that acceptable level of conduct may lead the regulators to assume that under the known conditions, there had been negligence on the part of the offender. This assumption leads to a determination of whether or not the performance of the accused has been less than acceptable and had relied on proper foresight and consideration of other parties to avoid injury and property damage. Even less prudent, and liable for criminal punishment, are those who fail to meet a required standard of conduct through violation of a mandatory rule set forth for the protection of public safety, as in the case of U.S. Coast Guard regulation.

A standard to minimize the number of steam boiler accidents was needed, but it was not until early 1900’s that such a standard was produced, and the standardization of the design, production, operation, maintenance, inspection, and testing of pressured products was finally accomplished. The standard, in this case called a code, generated by the American Society of Mechanical Engineers (ASME), has been considered one of the foremost achievements of U.S. engineering.

FRAMEWORK FOR APPLYING RISK-BASED METHODS IN MARITIME STANDARDS

The purpose of the framework is to provide a general structure to ensure consistent and appropriate application of Risk-Based Technology (RBT) methods. The principal parts of the framework, are identifying standards applications amenable to the use of RBT, addressing deterministic considerations, addressing probabilistic considerations, and integrating all of these elements. The first two parts are relatively well established. The principal focus of the CBST’s present effort is the development of the probabilistic considerations and integration of the deterministic and the probabilistic portions.

Conceptual Structure

As demonstrated by MSTEP the deterministic approach contains implied elements of probability or qualitative risk considerations from the chosen scenarios to be analyzed as design-basis scenarios.

RBT methods like Probabilistic Risk Assessment (PRA) address a broad spectrum of initiating events by assessing the event frequency. Mitigating system reliability is then assessed, including the potential for multiple and common cause failures. Therefore, the treatment goes well beyond the single failure requirements in the deterministic approach. The probabilistic approach to standardization is, therefore, considered an extension and enhancement of traditional standardization or regulation by considering risk in a more coherent and complete manner. A natural

outfalling of the increased use of RBT methods and techniques in shipbuilding is the focusing of standardization efforts on those items most important to productivity, in comparison to current efforts by the regulators of maritime industry to focus strictly on those items most important to safety. Where appropriate, RBT can be used to eliminate unnecessary conservatism and to support additional standardization requirements.

Deterministic-based regulations have been successful in protecting the public health and safety and RBT techniques are most valuable when they serve to bolster the traditional, deterministic-based regulations and support the defense-in-depth philosophy.

The RBT plan defined by the Center for Building Systems and Technologies, among other items, leads the staff efforts to convert this conceptual structure into practical guidance for the maritime industry using RBT in the formulation of maritime regulations. Key items in the plan to use RBT in maritime regulation development include the following identification of roles:

<u>CBST, U.S. Navy, and USCG</u> will develop decision criteria and in performing pilot studies of risk-based concepts for specific regulatory initiatives. CBST staff has received a number of ship-specific and system-specific requests from the U.S. Navy and commercial maritime interests for approval actions based on the findings of probabilistic risk assessments that will be used as pilot studies.

<u>U.S. Navy and USCG</u> will develop guidance for using RBT, in concert with decision criteria development work being performed efforts of above item. One element of the USCG's role is to develop a framework for risk-based regulations and RBT standards development.

This framework will be used in conjunction with ongoing proof-of-concept studies to provide an expert knowledge base capable of sustaining the use of RBT in a broad spectrum of industrial and regulatory activities. The framework described below is intended to ensure consistent approach towards the modification of existing standards and new regulatory decision-making processes. The resultant products will provide an in-depth understanding of each application thereby ensuring that consistent decisions are made.

The proposed framework has four parts:

(1) <u>Identification of both ongoing domestic and international regulatory activities</u>. The framework will allow to define those regulatory application areas in which RBT can play a role in the marine industry's decision-making process. These applications will be grouped by the expected level of RBT sophistication required. As necessary, these groups will be refined as new information and experience is available.

(2) <u>Categorization of problem areas to be addressed by deterministic approaches.</u> It is important to assure that current deterministic approaches are modified only after careful experimentation and review. Factors to be considered will include: the use of engineering principles based on research, test and analysis; the quality of the ship design, the ship production process and build strategy, operation and maintenance procedures; and the use and enforcement of appropriate codes and standards.

(3) <u>Categorization of problem areas to be addressed by probabilistic approaches</u>. There is a need to evaluate the probabilistic risk assessment issues in support of proposed regulatory actions within each application area. Key elements of this approach include:

- Use of established RBT methods (e.g., logic models, statistical analysis;
- Use of human and equipment reliability data from experience, testing and research;
- Use of appropriate scope and level of detail (e.g., modeling of accidents and mishaps);
- Uncertainty analysis; assurance of the technical quality (e.g., through review and approval by expert panels, peers or regulatory agencies); and
- Selection of appropriate risk metrics (e.g., oils spill frequency, amount of oil spilled, frequency of emergency shutdowns).

(4) <u>Integration of deterministic and probabilistic approaches</u>. A consistent and logical integration of the probabilistic and deterministic approaches is needed. The integration process may involve a reassessment of the bases of existing requirements. Such a reassessment would have access to a much-enhanced technical knowledge base in comparison to the one used to initially formulate the requirements. It would also take advantage of risk insights derived from recent probabilistic risk assessments. Successful completion of this portion of the process requires to have expert knowledge of both deterministic and probabilistic approaches. To accomplish this, University of Maryland in cooperation with the U.S. Coast Guard and the U.S. Navy has developed a six-step approach. The steps are listed below and illustrated in Figure 4.

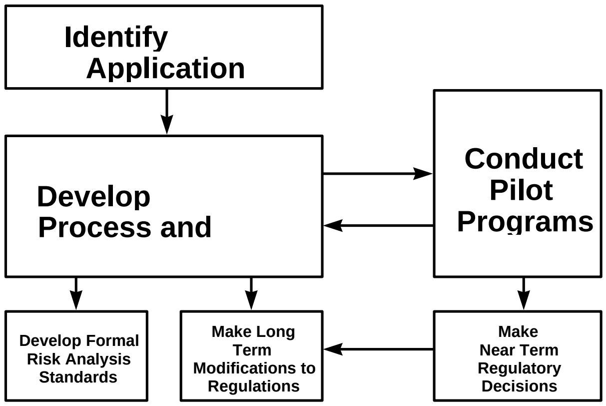

Figure 4. Six-step Process Associated with the RBT Methods in Maritime Standards Work.

(1) Identifying specific applications,
(2) Conducting pilot projects,
(3) Developing and documenting an acceptance process and criteria,
(4) Assisting the maritime industry in making near-term standards and regulatory decisions,
(5) Developing formal RBT standards, and
(6) Making modifications to existing standards and regulations as required.

Throughout this process, active participation of interested members of the public and industry are solicited.

Applications Receiving Industry Support

The process described above is being executed for a number of applications in parallel. One of these applications is the development of reliability-based design rules for ship structures. The development of a methodology for reliability-based design of ship structures requires the consideration of the following three components: (1) loads, (2) structural strength, and (3) methods of reliability analysis. Figure 5 (Ayyub et al 1995) shows an outline of a suggested methodology for reliability-based design of ship structures. Two approaches are shown in the figure: (1) Direct reliability-based design, and
(2) LRFD (load and resistance factor design) sheets. The three components of the methodology are shown in the figure in the form of several blocks for each. Also, the figure shows their logical sequence and interaction. The first approach can include both Level 2 and/or Level 3 reliability methods. Level 2 reliability methods are based on the moments (mean and variance) of random variables. Whereas, Level 3 reliability methods use the complete probabilistic characteristics of the random variables. In some cases, Level 3 reliability analysis is not possible because of the lack of complete information on the full probabilistic characteristics of the random variables. Also, computational difficulties in Level 3 methods sometimes detract from their uses. The second approach (LRFD) is called a Level 1 reliability method. Level 1 uses reliability-based safety factors; but the method does not require an explicit use of the probabilistic description of the variables.

The two reliability-based design approaches start with the definition of a mission and an environment for a ship. Then, the general dimensions and arrangements, structural member sizes, scantlings, and details need to be assumed. The weight of the structure can then be estimated to ensure its conformance to a specified limit. Using an assumed
operational-sea profile, the analysis of the ship produces both a stochastic stillwater and wave-induced responses. The resulting responses can be adjusted using uncertainty-modeling estimates that are based on available full-scale or large-scale testing results. The two approaches, beyond this stage, proceed in two different directions.

The direct reliability-based design approach requires performing analysis of the loads. Also, linear or nonlinear structural analysis can be used to develop a stress frequency distribution. Then, stochastic load combinations can be performed. Linear or nonlinear structural analysis can then be used to obtain deformation and stress values. Serviceability and strength failure modes need to be considered at different levels of the ship, i.e., hull girder, grillage, panel, plate and detail. The appropriate loads, strength variables, and failure definitions need to be selected for each failure mode. Using reliability assessment methods, failure probabilities for all modes at all levels need to be computed and compared with target failure probabilities.

The LRFD sheets approach requires the development of response (load) amplification factors, and strength reduction factors. The development of these factors is shown in Figure 6 (Ayyub et al 1995) using a reliability analysis that is called a calibration of design sheet. Figure 5 shows the use of these factors in reliability-based design. The load factors are used to amplify the response, and strength factors are used to reduce the strength for a selected failure mode. The implied failure probabilities according to these factors are achieved by satisfying the requirement that the reduced strength is larger than the amplified response. The LRFD can, therefore, be used by engineers without a direct use of reliability methods. The background reliability effort in developing these factors is shown in Fig. 6.

The above two approaches require the definition of a set of target reliability levels. These levels can be set based on implied levels in the currently used design practice with some calibration, or based on cost benefit analysis. Also, the consequence aspect of risk can be considered according to this method by using different target reliability levels that are linked to corresponding consequence levels. Additional details on this application are provided by Ayyub et al (1995).

Related Industry Activities

The maritime industry has a number of efforts underway which directly relate to the work being done at the University of Maryland. Among them is the International Maritime Organization FSA (Formal Safety Assessment) methodology and the U.S. Coast Guard's MSTEP (Marine Safety Evaluation Program). The FSA is aimed at the support of IMO's standards development process. A new organizational unit of the U.S. Coast Guard known as the National Maritime Center is performing MSTEP, the largest of these programs. The impetus for MSTEP was the need to address industry's requests for repeatable safety determinations and consistent regulatory process reforms

and improvements.

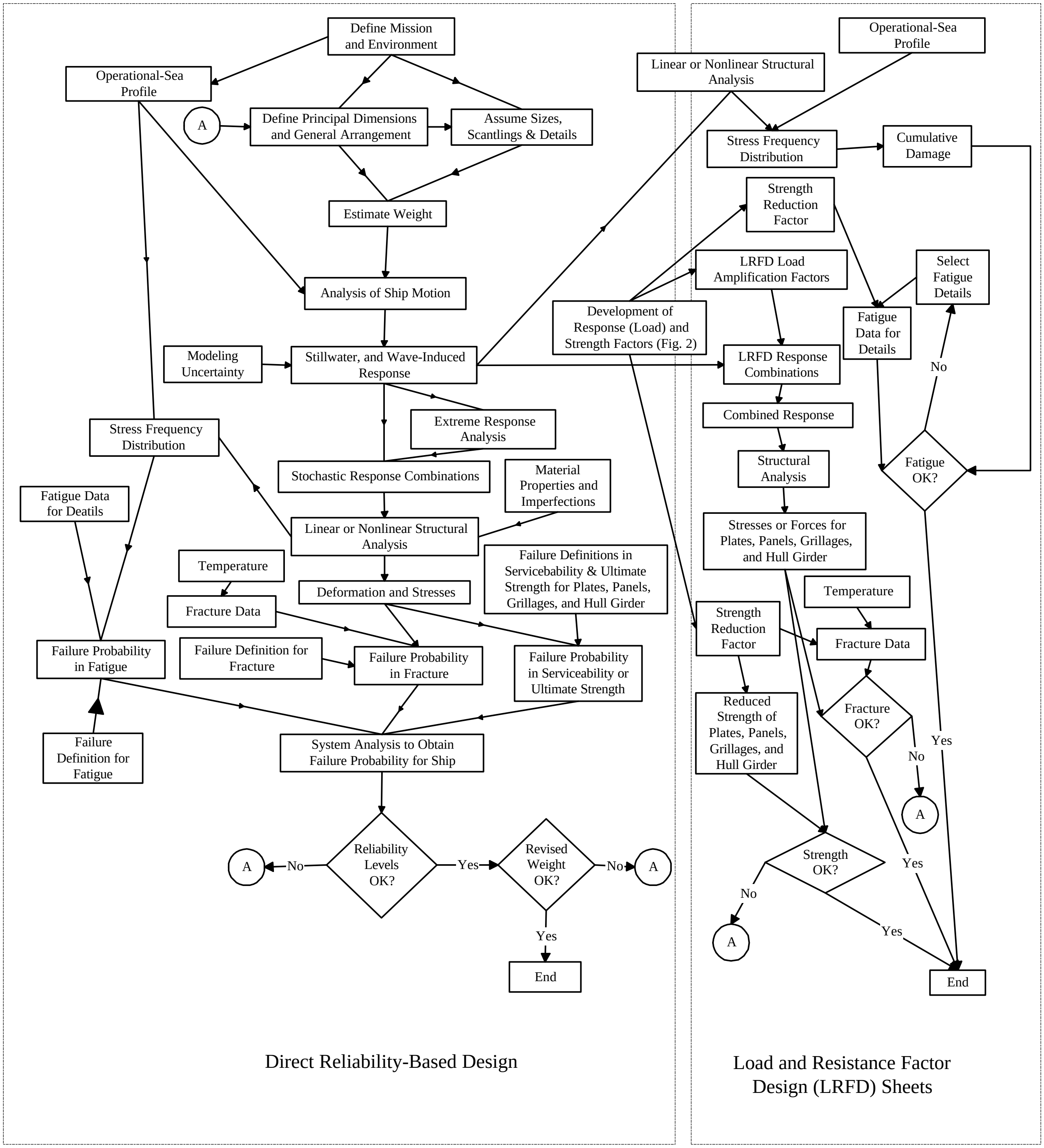

Figure 5. Reliability-Based Design of Ship Structures (Ayyub et al 1995)

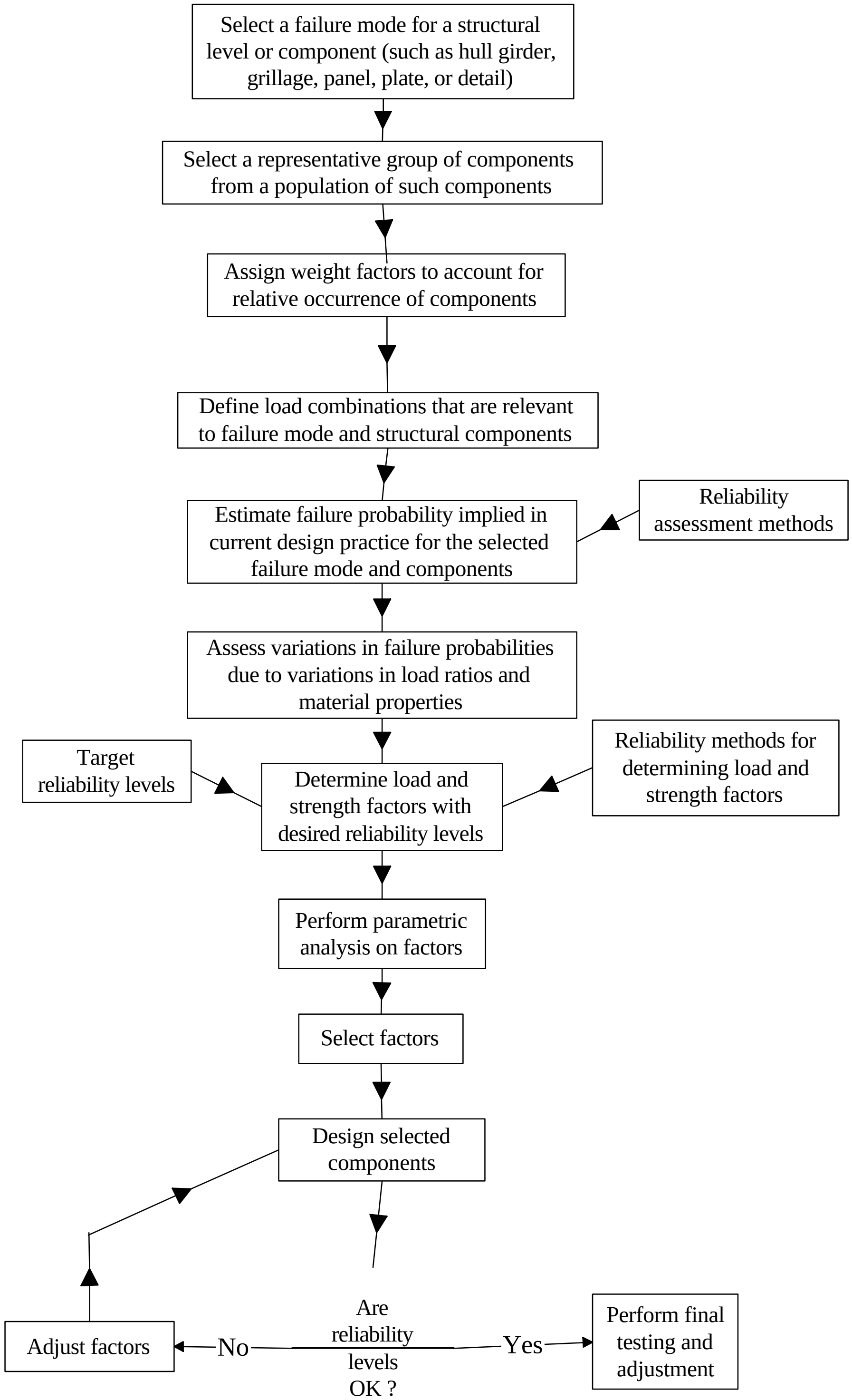

Figure 6. Calibration of Design Sheets (Ayyub et al 1995)

The MSTEP is a new initiative advanced by the U.S. Coast Guard and marine industry. MSTEP has far reaching implications, not only to the industry but to the government as well. Once fully developed, MSTEP will provide industry and government with the ability to further improve their safety assessments for equipment and shipboard systems and allow for proactive regulation reform, development and application.

Initially, one view of the MSTEP concept was that it was a process for applying design and engineering criteria found in existing international marine standards to U.S. marine equipment. This was a rather narrow view. A broader view has now been taken that encompasses a robust systems design and engineering assessment capability. This approach will allow for the formulation and of system-based safety assessment capability. Also, it will allow for the formulation, application, assessment, modification, maintenance and storage of system-based safety criteria for consideration throughout the life cycle of the ship.

RISK-BASED STANDARDS

The transition of the marine industry to risk-based standards will take place gradually. If the observations of the nuclear power industry are any indication the greatest burden to the marine industry, at least in the short term, may be found in the duality of trying to apply both existing practices and RBT methods simultaneously. The most important factor for success will be the commitment that the marine industry and its regulators have towards changing in the direction of risk-based standards. What is needed to aid this process is the basis for measuring the progress of the industry towards its risk-based goals. In addition, the industry must devise a series of mechanisms for demonstrating that its compliance with these goals attains a level of safety that will be approved by its regulators.

With the advent that risk-based assessments will be available throughout the industry and the government there is a need for consistent decision criteria that accept such results as a form of alternative compliance. There is a need for action to be taken by the marine industry and its regulators to establish the basis for risk-based acceptance criteria. This may be achieved by forming regulatory review groups that will conduct a review of existing marine regulations with an eye towards reducing unnecessary regulatory burden by adopting risk-based results as a sustainable alternative.

The University of Maryland is at the forefront of identifying quality assurance, in-service inspection and testing criteria necessary for the formulation of a comprehensive marine standards development plan based on proven RBT concepts. In addition, the university is involved in providing source material and recommendations on the use of RBT methods relating to risk-based standards to the U.S. Coast Guard.

These efforts are aimed at building a clear consensus on the merit of a risk-based standardization process. While the advantages of RBT have already been demonstrated to the government and industry, there remains reluctance on the part of the bureaucracy to mandate risk- compliance as an acceptable alternative for all current and future federal regulations.

LESSONS-LEARNED TO DATE

The need to assess safety risk resulting from shipboard hazards has focused attention in recent years on collection and interpretation of operational data. Operational risk assessments are used to determine the need for safety actions and to communicate to the industry the significance of risks from exposure to hazards. They may also be used to determine the effectiveness of actions taken to reduce risk. Standards and guides for assessing marine risk are being currently developed, most notably by the U.S. Coast Guard with support from the U.S. Navy’s Mid-Term Sealift Program. Generally, risk assessment practices are determined by a combination of factors including scientific and technical knowledge, the level of experience of risk assessors, specifics of the system under analysis, industry concerns and marine regulations and guidance.

There are at least two competing factors associated with the application of risk assessment that have encouraged activities at the U.S. Coast Guard and the U.S. Navy. First, it is generally useful and prudent to standardize technical practices of risk assessment process. Standardization of risk assessment methodologies would enhance uniformity, consistency, and communication of policy issues. For example, a standard defining an acceptable increase in the lifetime risk of hearing loss resulting from exposure to shipboard noise is a policy issue. Second, it is often necessary to adjust the risk assessment process to local or regional conditions associated with the potential marine hazards. Numerous shipboard system types, operational schemes, and variety of cargoes can have an impact on the overall assessment of the ship safety.

The challenge for maritime community is to develop standard guides and practices that have enough flexibility to accommodate both factors. Because of the complexity of marine risk assessments and the need to consider risk to human health and the environment, a multidisciplinary approach is essential. Risk

assessment of marine hazards is not a technical discipline itself but requires expertise from numerous technical areas. For example, a few of the disciplines that may be required include psychology, chemistry, statistics and toxicology. Although human health and equipment hazard risk assessments can be and often are developed separately, some amount of information to support them may be the same, and decisions concerning actions to be taken can be influenced by both.

Several project teams made of industry, government and academia are actively involved in developing guides and practices relevant to shipboard hazards. Among them are MARAD's RO/RO Cargo Hold Lighting analysis team, U.S. Coast Guard's Diesel-Generator analysis team, MAN's Four-Stroke and Two-Stroke Diesel Engine analysis teams, and SIEMEN's Shipboard Electric Power Generation Systems analysis teams. The U.S. Coast Guard in cooperation with the Mid-Term Sealift Program Office and the American Society of Mechanical Engineers (ASME) held a Risk-Based Technology (RBT) Workshop in December of 1995. It included members of the marine safety consulting, regulatory, ship classification, academia and industrial community. The majority of the participants agreed that the marine risk-based standards should address both the equipment (systems) and human factors risk assessments.

Since the first marine RBT workshop the U.S. Coast Guard has identified topics from which standard guides and practices are being developed. Several topics regarding marine risk assessment where standards are under development are Preliminary Hazard Assessment (PrHA) of Diesel-Generator System, PrHA of Four-Stroke Diesel Engine System, PrHA of Two-Stroke Diesel Engine System, and a set of PrHAs of Shipboard Electric Power Generation Systems. The PrHA is a top-down approach that defines the hazards, accident scenarios, and risks of a particular process or system. Its purpose is to develop a rank-ordered list of major risk contributors to the system under study. The results from applications of the PrHAs allow management to concentrate their efforts and resources on those areas that have the highest consequence and frequency of hazard. It provides management with a logical basis for balancing the safety risk and economic impact of regulation. These activities are closely coordinated with the industry, U.S. Coast Guard and the major sponsor – the U.S. Navy. A primary goal of the Navy's Mid-Term Sealift Program has been to provide the U.S. Coast Guard and the marine community with a forum and resources so the marine risk assessment issues can be openly addressed by all members of the risk assessment community and new risk-based standards and standard development methods can be evolved.

The major intellectual advancement, or revelation, made by Navy's MTSSTDP Global Standards task on behalf of the marine industry is that the current state of the art for assessing risk of shipboard systems consists of adopting existing forms of failure mode analysis to individual pieces of equipment in complex system environment. In many cases this approach is not capable of assessing risk factors associated with system linkages, both mechanical and operational, and thereby doesn't adequately simulate a real operating environment for these systems. In addition environmental factors such as temperature, humidity, air quality, vibration and noise cannot be factored into existing risk assessment tools. This is evidenced by the controversial study provided by the Japanese classification society, NKK, published in 1995, that attributed the high incidence of engine room fires on oil tankers to vibration-induced failure of fuel oil line joints and couplings.

Advances acceptance on the part of classification societies for individual components of shipboard systems without any ability to place, or simulate, the component within a 'real' system environment where as many operational conditions are accounted for as possible will invariably lead us to the wrong conclusion pertaining to the primary risk contributors within shipboard distributive systems. This was evidenced by several NSRP projects that intended to get U.S. Coast Guard 'pre-approval' of individual system components for use in future commercial shipbuilding designs without any consideration of where the true risks resided within typical shipboard system designs in which these components will reside. For example, pre-approval of electrical switches within a system where the valves are truly the high risk component will gain no increase in overall system safety and only serve to increase system costs. Early qualitative ship-wide system assessments can avert this situation from accurring as was evidenced by the MARAD sponsored RO/RO cargo hold lighting system investigation. Until computers are capable of simulating all operational and environmental aspects of complex marine systems shipboard operational data will remain as the singularly most important element in the proper formulation and execution of these early ship-wide system risk assessments.

CONCLUSIONS

The maritime industry realizes that there is a need for guidelines and standards on the selection, design and operation of shipboard systems. The task of writing such standards, however, is difficult because there are two separate coalitions regarding the analysis of such systems. Differences of opinion, regarding how risk is measured, how system performance is measured, and how the two can be related, makes widespread standardization impractical. Part of the current industrial dilemma focuses on both the qualitative and quantitative methods of assessing risk. To further cloud the picture both offer benefits as well as drawbacks. Qualitative methods offer easily understood "cook-book" results, but the intuitive and subjective process result in considerable differences by virtually all who use it. Quantitative analysis on the other hand requires more engineering manpower and provides a more common ground of understanding among different individuals, yet it has gained little acceptance by those who have a distrust of statistical methods. A blend of the two methods represents a realistic compromise that would allow the marine industry and the government to combine their efforts and achieve a mutually beneficial set of objectives in the not so distant future.

The technology of risk-based approaches as they

apply to safety determinations is complex. This complexity has led to these approaches being viewed as unacceptable by many of the current stakeholders in the marine safety process. As a matter of fact the lack of acceptance of risk analysis is frequently attributed to the inherently poor communication of risk within our current safety determination methods.

It is up to the industry to make risk-based standards work. They can do this by taking the initiative to make alternative compliance based on risk assessments acceptable to the U.S. Coast Guard. This can be achieved by working with the U.S. Coast Guard and assisting them to recognize outdated and ineffective standards and regulations. Risk-based standards would then be jointly developed to either supercede or eliminate the existing standards that have been deemed obsolete.

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